Changes in the relative abundance of ring-necked pheasants (*Phasianus colchicus*) in relation to protected areas.

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1 Abstract

Millions of Ring-necked pheasants (*Phasianus colchicus*) are released for shooting annually in the UK. Management aims to keep the majority of birds within the bounds of the shoot but dispersal into the wider landscape can occur, especially when management decreases after the shooting season. Protected areas might be sites that dispersing pheasants are attracted to as they may provide respite from shooting and may provide suitable habitat for overwintering and/or breeding. Using survey data from four county bird atlases during 2007-2011, we assessed whether there were shifts in pheasant abundance towards areas with high protected area coverage, and whether this shift is consistent between winter and the breeding season, as well as across counties. We used an occupancy-abundance model to examine the relationship between relative pheasant abundance and protected area coverage. We found a negative relationship between relative pheasant abundance and protected area coverage that was consistent between winter and the breeding season across all counties, suggesting that pheasants do not use preferentially use protected areas as refuges and overwintering/breeding sites. There are some important caveats to this work that we highlight, including the use of coarse categorical data, spatial autocorrelation in the model and the assumption of constant survival within counties.

2 Introduction

Ring-necked pheasants (*Phasianus colchicus*) are released across the UK for hunting during the shooting season, which runs from October until February. After release, pheasants can move away from the release sites (Hill and Ridley 1987) but game management aims to keep the majority of pheasants within areas where shooting will take place (Game Conservation Trust, 1996). Protected areas (special areas of conservation, sites of special scientific interest, special protection areas) may be attractive to dispersing individuals, providing a refuge from shooting activities or providing suitable wintering/breeding habitats. Such immigration may be concerning because of the ecological change that these birds may exert via direct negative effects including nutrient enrichment through defecation, predation of local native fauna, trampling damage to flora, being potential vectors of disease and/or supporting local abundances of generalist predators (Madden and Sage 2020; Mason et al. 2020; Sage et al. 2020). One way to assess whether released pheasants are moving into protected areas is to examine whether there are shifts in the relative abundance of pheasants from areas where they are released and retained (late-summer to late winter), towards protected areas in the breeding season (late spring/early summer) after shooting and game management has predominantly ceased.

During 2007-2011, the BTO organised volunteer surveys of all UK birds at the tetrad level (2km x 2km squares) during the winter (November to February) and breeding season (April to July; Balmer et al. 2013). Fieldwork for the survey was carried out in four winters (2007/08–2010/11) and four breeding seasons (2008–11) with a pair of standardized visits to each tetrad in each of the eight survey periods (for more details on the methodology see Balmer et al. 2013; Gillings et al. 2019). These data provide an abundance estimate for pheasants during the winter and breeding season. Changes in abundance can therefore be examined between winter, when shooting typically takes place, and summer, when breeding takes place but the next cohort of reared pheasants have yet to be released. Between these two time periods the number of pheasants will have decreased overall due to natural mortality and shooting to approximately 15% of those released (Madden, Hall, and Whiteside 2018). Therefore, we are interested in changes in the relative abundance which accounts for mortality. If pheasants are dispersing towards protected areas then we would expect increases in the relative abundance between winter and summer in tetrads containing a higher percentage coverage of protected areas.

3 Methods

3.1 Pheasant abundance data

Several UK counties conduct tetrad surveys of their bird fauna and publish their results. We collated data from four counties who published their atlases online. Berkshire (http://berksoc.org.uk/county-atlas/), Cornwall (https://atlas.cbwps.org.uk/), Devon (http://devonbirdatlas.org/) and Hertfordshire (http://www.hertsatlas.org.uk/). For each of these atlas', data were collected on the abundance of birds in 2km^2 tetrads during the breeding season (April to July) and winter period (November to February), following methods used by the British Trust for Ornithology (BTO) as part of their Atlas surveys (Balmer et al. 2013, Gillings *et al*. 2019). In Berkshire, data were collected from 394 tetrads between 2007 and 2011. In Cornwall, data were collected from 1050 tetrads between 2000 and 2009. In Devon, data were collected from 1858 tetrads between 2007 and 2013. In Hertfordshire, data were collected from 491 tetrads between 2007 and 2012. We standardised data across counties since it was publicly reported differently in each county. Abundance data were continuous for Cornwall and remained unaltered. For Devon, Berkshire and Hertfordshire, abundance was categorical and these categories were different for each of the three counties. We therefore calculated the midpoint value for each category, meaning each tetrad had a single continuous value of abundance for winter and summer.

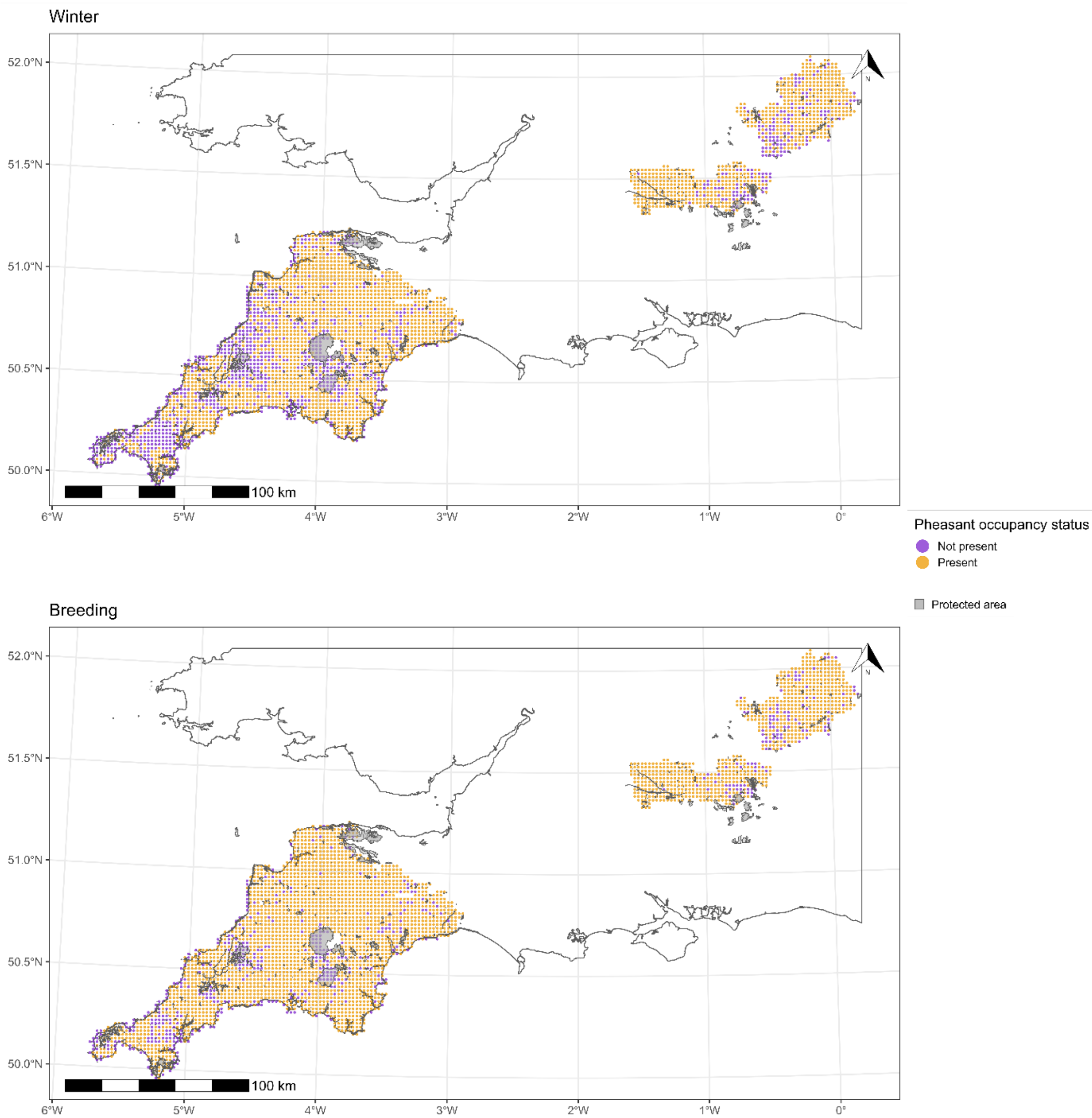

Figure 1- the pheasant occupancy status of each 2km² tetrad in Berkshire, Cornwall, Devon and Hertfordshire in winter and during the pheasant breeding season. Protected areas of suitable habitat are overlayed in grey.

During the winter period, the released birds are being actively managed by gamekeepers for shooting, being retained on the releasing estate for the shooting season by feeding, habitat management or direct driving. During the breeding season, the birds that survived the shooting season may attempt to breed and gamekeepers are less motivated to retain them on the estate. The next cohort of reared pheasants are released in late summer. Between winter and the breeding season, the number of pheasants will have decreased overall due to natural mortality and shooting to ~15% of those released (Madden, Hall, and Whiteside, 2018). We were interested in changes in abundance relative to the total sample of pheasants alive in each county, accounting for these high levels of mortality and mass releases in late summer. Therefore, we calculated a relative abundance metric that accounted for the abundance of pheasants alive in a county in a season, taking into account the high levels of mortality from winter to breeding or the marked increases due to releases from the breeding season to winter. We converted all abundance measures into relative abundance measures using the following equation:

$$A'_{i,c,s} = \frac{A_{i,c,s}}{\sum_{i=1}^{N_c} A_{i,c,s}} \qquad 1$$

where $A_{i,c,s}$ and $A'_{i,c,s}$ denote the absolute and relative abundance metric for the ith tetrad in county c during season s, respectively. N_c denotes the total number of tetrads in county c. This relative abundance metric would be constant for a given tetrad if there is no net immigration or emigration and survival is constant across the county.

If pheasants are dispersing towards protected areas, then we would expect evidence of an interaction between the effect of protected area coverage and season on relative pheasant abundance. If this is the case, we would expect the effect of protected area coverage to be more positive in the breeding season than in winter (when pheasant dispersal is still being managed).

3.2 Tetrad data

Across the four counties examined we calculated the proportion of each 2km x 2km tetrad (n = 3442) covered by protected areas that were ecologically relevant to pheasants. We used the 2007 United Kingdom Centre for Ecology and Hydrology (UKCEH) land cover map (25m x 25m spatial resolution; Morton *et* al., 2014) to determine the dominant habitat type in each protected area. Protected areas were classified as ecologically irrelevant to pheasant and removed from subsequent analysis if the dominant habitat type was one of the following: ocean, saltwater, freshwater, saltmarsh, bog, urban, suburban, inland rock, supra-littoral sediment, supra-littoral rock, littoral sediment or littoral rock. This meant protected areas mostly taken up by the following habitat types were retained: broadleaved woodland, coniferous woodland, arable/horticulture, fen/marsh/swamp, heather, heather grassland, acid grassland, rough grassland, improved grassland, neutral grassland and calcareous grassland. These remaining habitats are where pheasants are most commonly found in breeding bird surveys (Heywood *et al*. 2023). Occasionally a single designated site was composed of multiple distinct and disconnected polygons. In these instances, the dominant habitat type in each polygon was calculated and areas excluded or included at the polygon level.

Secondly, we calculated the proportion of each tetrad covered by each of 10 aggregate habitat classes: broadleaf woodland, coniferous woodland, arable, improved grassland, semi-natural grassland, mountain heath & bog, saltwater, freshwater, coastal and built-up areas and gardens (Morton *et* al., 2014). We also calculated the Shannon diversity index for each tetrad. This is calculated as $H' = -\sum_{i=1}^{n} p_i \times \ln(p_i)$, where p_i is the proportion of each tetrad taken up by the ith habitat type, and n is the total number of possible habitat types (Ortiz-Burgos, 2016). Higher values of H' indicate more habitat types in a tetrad.

3.2 Statistical analyses

To analyse the relationship between protected areas and the relative abundance of pheasants, we used an occupancy-abundance model in a Bayesian framework. These models are a mixture of occupancy models, which simultaneously estimate the probability a target species occupies a given area and a probability of target species detection, and abundance models, which estimate the abundance of the target species in occupied areas (modelled using a Beta distribution; Bailey *et al*., 2014, Holt *et al*., 2002, Potts & Elith, 2006). We can also estimate the effects covariates have on pheasant abundance to determine what features of a tetrad causes pheasant abundance to increase or decrease. Using these models allows us to estimate and account for the probability that pheasants were present in a tetrad but were not detected during surveys.

The fixed effects included in the model were county (Cornwall, Devon, Berkshire, Hertfordshire), time period (winter/breeding season), the proportion of each tetrad covered by each of the 10 habitat types (detailed in section 3.2, one fixed effect for each habitat type), and the proportion of each tetrad covered by ecologically-relevant protected areas. We included a two-way interaction term between time period and protected area coverage, to determine if the effect of protected area coverage differs between the winter period and breeding seasons. We also included a three-way interaction between county, time period and protected area coverage to account for possibility that the effect of protected area coverage and its interaction with time, may be different for each county.

All models were written in Stan (Carpenter *et al*., 2017) and compiled using Cmdstan (Stan Development Team, 2018) and the *cmdstanr* package (version 0.8.0; Gabry & Johnson, 2023) in R (version 4.4.0; R Core Team, 2022) using RStudio (version 2024.09.0; RStudio Team, 2020). Weakly informative priors were used for all parameters, and model convergence was checked by inspecting trace plots and ensuring that the potential scale reduction factor ($\hat{R}$) ≈ 1. The 2.5% and 97.5% highest density limits (HDL) of posterior distributions are reported in square brackets throughout (e.g. [-0.01, 0.01]; Kruske, 2014, McElreath, 2020). More information on the priors used, as well as the full model output can be found in the supplementary materials.

4 Results

4.1 Counties

Relative pheasant abundance varied by county with Devon having the lowest per tetrad (estimated mean relative abundance = [0.0005, 0.0006]) and Berkshire having the highest per tetrad (estimated mean relative abundance = [0.0009, 0.001]). A summary of the estimated mean relative abundance for each county can be found in table 1.

County	2.5% HDL of mean relative abundance	97.5% HDL of mean relative abundance
Berkshire	0.0009	0.001
Cornwall	0.0006	0.0007
Devon	0.0005	0.0006
Hertfordshire	0.0008	0.0009

Table 1- the estimated mean relative abundance of pheasants for each of the counties included in the study.

4.2 Habitat type

The most prevalent effect on pheasant abundance was caused by the 10 habitat types. There were positive relationships between abundance and the proportion of each tetrad occupied by broadleaf woodland (β = [0.07, 0.15]), and arable (β = [0.08, 0.18]). The proportion of each tetrad occupied by mountain, heath and bog (β = [-0.11, -0.006]), built-up areas (β = [-0.19, -0.10]), freshwater (β = [-0.07, -0.01]), and semi-natural grassland (β = [-0.11, -0.004]) had a negative relationship with pheasant abundance. A summary of the relationship between relative pheasant abundance and all 10 habitat types can be found in table 2. The effect of broadleaf woodland coverage on relative pheasant abundance is shown in figure 2.

Habitat type	2.5% HDL of effect size	97.5% HDL of effect size
Broadleaf woodland	0.07	0.15
Coniferous woodland	-0.04	0.02
Arable	0.08	0.18
Improved grassland	-0.05	0.05
Semi-natural grassland	-0.11	-0.004
Mountain, heath and bog	-0.11	-0.006
Saltwater	-0.03	0.04
Freshwater	-0.07	-0.01
Coastal	-0.05	0.02
Built-up areas and gardens	-0.19	-0.10
Shannon habitat diversity index	-0.03	0.04

Table 2 - shows the highest density limits (HDL) of the posterior distribution of the effect size of the proportion of each tetrad occupied by all 10 UKCEH land-use habitat types, as well as the effect of the Shannon habitat diversity index.

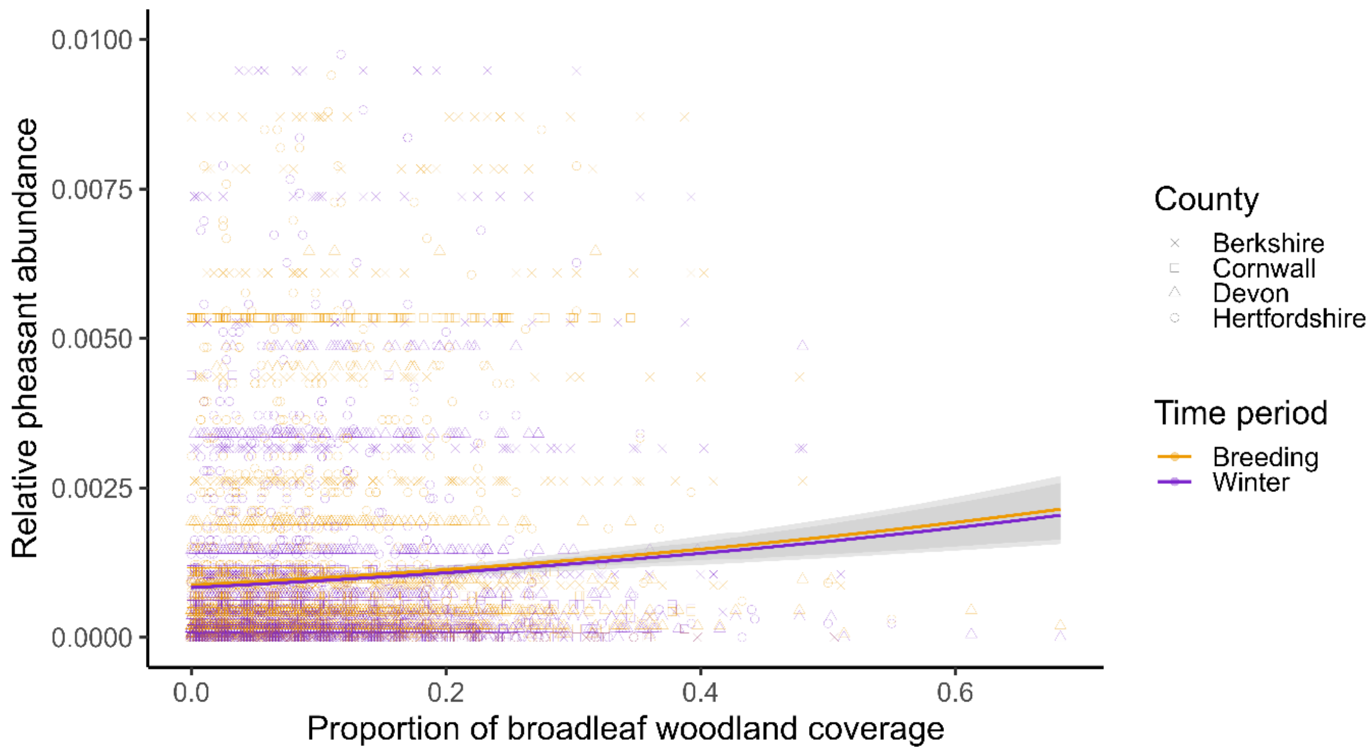

Figure 2- the raw pheasant relative abundance data (coloured points) and the model predicted relationship between the proportion of broadleaf woodland coverage and mean relative pheasant abundance (coloured lines). The grey shaded areas denotes the 95% highest density interval for each time period.

4.3 Protected area coverage

There was evidence of a negative effect of the proportion of each tetrad occupied by protected areas on pheasant abundance (β = [-0.12, -0.03], see figure 3). However, there was no evidence of a two-way interaction between protected area coverage and time period (β = [-0.81, 0.80]), suggesting the effect of protected area coverage is consistent between winter and the breeding season. There is also no evidence to suggest a three-way interaction between protected area coverage, time period, and county (see table 3).

Fixed effect	2.5% HDL of effect size	97.5% HDL of effect size
Protected area (PA) coverage	-0.12	-0.03
Time period: Winter → Breeding	0.01	0.04
PA coverage × Time period: Winter → Breeding	-0.81	0.80
PA coverage × Time period: Winter × Berkshire	-1.60	1.61
PA coverage × Time period: Winter × Cornwall	-1.46	1.45
PA coverage × Time period: Winter × Devon	-1.55	1.47
PA coverage × Time period: Winter × Hertfordshire	-1.42	1.42
PA coverage × Time period: Breeding × Berkshire	-1.68	1.70
PA coverage × Time period: Breeding × Cornwall	-1.48	1.45
PA coverage × Time period: Breeding × Devon	-1.37	1.57
PA coverage × Time period: Breeding × Hertfordshire	-1.38	1.44

Table 3- shows the highest density limits (HDL) of the posterior distribution of the effect size of the proportion of each tetrad occupied by suitable protected areas, the time period in which the abundance survey took place, as well as the two- and three-way interactions between protected area coverage, time period and county.

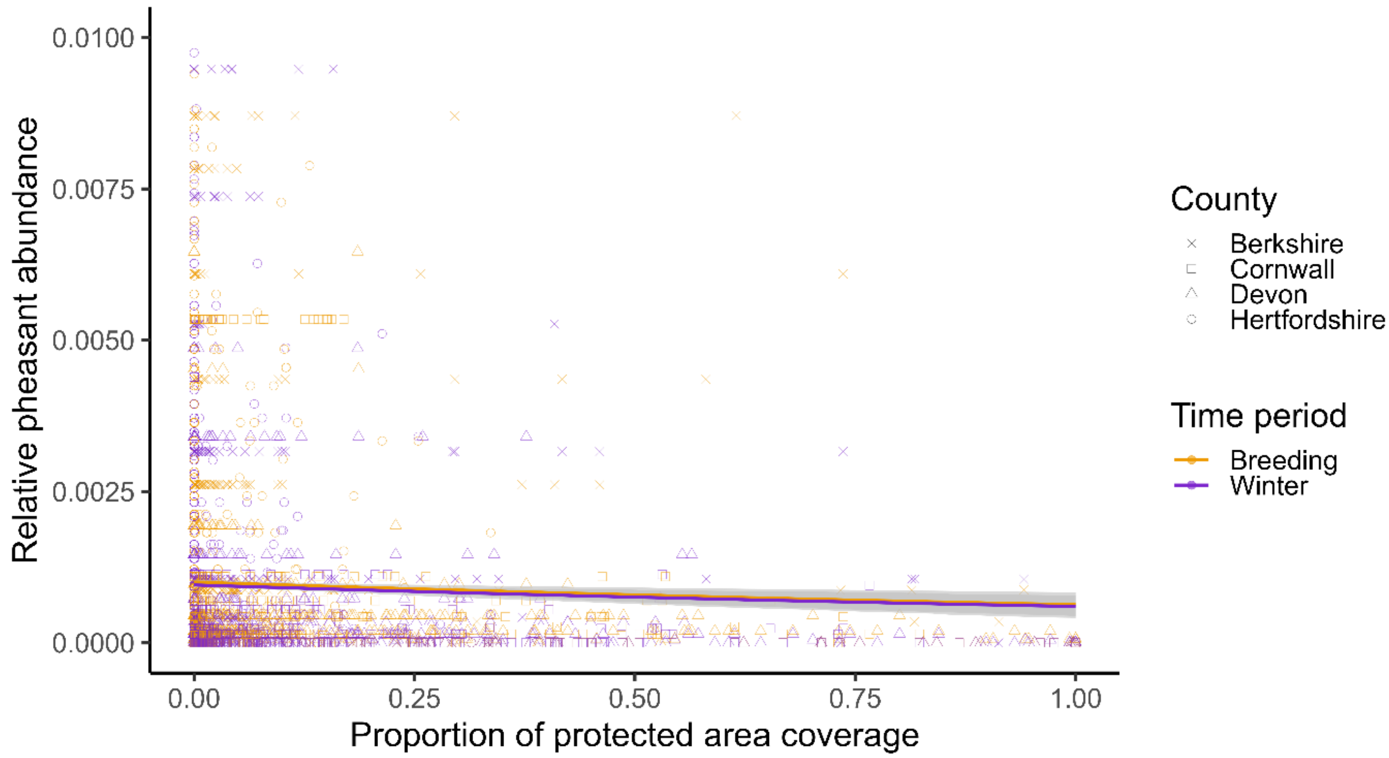

Figure 3- the raw pheasant relative abundance data (coloured points) plotted over the amount of each tetrad occupied by suitable protected areas. The predicted relationship between protected area coverage and mean relative abundance is shown (coloured lines). The grey shaded areas show the 95% highest density interval.

The full results from the occupancy-abundance model can be found in the supplementary materials.

5 Discussion

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Supplementary materials

Parameter	Posterior mean	5% quartile	95% quartile	R-hat	Bulk ESS	Tail ESS	Prior distribution
P(detection)	0.79	0.78	0.8	1	9419	2922	N(0.5, 1)
P(occupied)							
Population mean	0.83	0.82	0.83	1	8140	3063	N(0, 1)
Standard deviation	0.07	0.01	0.16	1	1667	2072	Exp(1)
Mean relative abundance							
Intercept							
Population mean	0.001	0.0009	0.001	1	2795	3367	N(0, 1)
Standard deviation	0.51	0.48	0.53	1	998	1836	Exp(1)
Fixed effect							
County: Cornwall	-0.36	-0.4	-0.32	1	2849	3054	N(0, 1)
County: Devon	-0.58	-0.61	-0.54	1	2560	2784	N(0, 1)
County: Hertfordshire	-0.1	-0.12	-0.07	1	3035	3090	N(0, 1)
Time period: Winter → Breeding	0.02	0.01	0.04	1	6771	3797	N(0, 1)
Broadleaf woodland	0.11	0.08	0.14	1	2639	2757	N(0, 1)
Coniferous woodland	-0.01	-0.04	0.01	1	3324	3211	N(0, 1)
Arable	0.13	0.08	0.17	1	2446	2963	N(0, 1)
Improved grassland	0	-0.04	0.04	1	2930	3168	N(0, 1)
Semi-natural grassland	-0.05	-0.1	-0.01	1	2837	3303	N(0, 1)
Mountain, heath and bog	-0.06	-0.11	-0.02	1	3545	3396	N(0, 1)
Saltwater	0	-0.03	0.03	1	4550	2817	N(0, 1)
Freshwater	-0.04	-0.07	-0.02	1	4247	3473	N(0, 1)
Coastal	-0.02	-0.05	0.01	1	3514	3180	N(0, 1)
Built-up areas and gardens	-0.14	-0.18	-0.1	1	2620	2646	N(0, 1)
Shannon habitat diversity index	0.01	-0.02	0.04	1	2900	3259	N(0, 1)
Protected area (PA) coverage	-0.07	-0.11	-0.03	1	3768	2660	N(0, 1)
PA coverage × Time period: Winter → Breeding	0.02	-0.64	0.69	1	5925	2892	N(0, 1)
PA coverage × Time period: Winter × County: Berkshire	-0.01	-1.34	1.41	1	9127	3270	N(0, 1)
PA coverage × Time period: Winter × County: Cornwall	-0.01	-1.26	1.26	1	6660	2781	N(0, 1)
PA coverage × Time period: Winter × County: Devon	-0.01	-1.34	1.41	1	7618	2661	N(0, 1)
PA coverage × Time period: Winter × County: Hertfordshire	-0.02	-1.22	1.2	1	7223	3295	N(0, 1)
PA coverage × Time period: Breeding × County: Berkshire	0.01	-1.42	1.44	1	7589	2762	N(0, 1)
PA coverage × Time period: Breeding × County: Cornwall	-0.01	-1.27	1.25	1	6401	2911	N(0, 1)
PA coverage × Time period: Breeding × County: Devon	-0.01	-1.25	1.24	1	7272	2904	N(0, 1)
PA coverage × Time period: Breeding × County: Hertfordshire	0.03	-1.17	1.25	1	7441	2813	N(0, 1)
Family-specific parameters							
Precision (phi)	1167.46	1109.49	1226.11	1	1660	2959	Exp(1)

Table 4- the full model output from the occupancy-abundance model, showing the posterior mean, 5% quartile, 95% quartile, R-hat, bulk estimated sample size (ESS), and tail ESS. The prior distribution used for each parameter is also shown.